

# UNCLASSIFIED

AD NUMBER
AD870696
NEW LIMITATION CHANGE
TO Approved for public release, distribution unlimited
FROM Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; JUN 1970. Other requests shall be referred to Air Force Rocket Propulsion Lab., Edwards AFB, CA.
AUTHORITY
AFRPL ltr, 29 Sep 1971

THIS PAGE IS UNCLASSIFIED

AFRPL-TR-70-63

(20)  
E

AD No. \_\_\_\_\_  
AD870696

DDC FILE COPY

**TEST FIRING  
OF  
A SUPERSONIC PROBE THRUST  
VECTOR CONTROL CONCEPT**

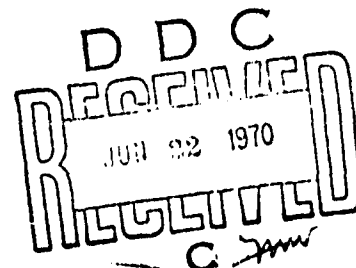
**J. R. ELLISON, LT, USAF**

**TECHNICAL REPORT AFRPL-TR-70-63**

**JUNE 1970**

THIS DOCUMENT IS SUBJECT TO SPECIAL EXPORT CONTROLS AND EACH TRANSMITTAL TO FOREIGN GOVERNMENTS OR FOREIGN NATIONALS MAY BE MADE ONLY WITH PRIOR APPROVAL OF AFRPL (RPOR/STINFO) EDWARDS, CALIFORNIA 93523.

**AIR FORCE ROCKET PROPULSION LABORATORY  
AIR FORCE SYSTEMS COMMAND  
UNITED STATES AIR FORCE  
EDWARDS, CALIFORNIA**



**Best  
Available  
Copy**

ACCESSION BY	
WFO	WHITE SECTION <input type="checkbox"/>
DOC	DIFF SECTION <input checked="" type="checkbox"/>
UNCLASSIFIED	<input type="checkbox"/>
JUSTIFICATION	
BY	
DISTRIBUTION/AVAILABILITY CODES	
REST.	AVAIL. GEN. OR SPECIAL
2	

# NOTICES

When U. S. Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, or in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

AFRPL-TR-70-63

TEST FIRING OF A SUPERSONIC PROBE THRUST  
VECTOR CONTROL CONCEPT

John R. Ellison, Lt, USAF

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of AFRPL (RPOR-STINFO), Edwards, California 93523.

## FOREWORD

This report was prepared by the Motor Component Development Branch, Solid Rocket Division, Air Force Rocket Propulsion Laboratory (AFRPL). The subject test was conducted under Project 305903 AMG, Solid Rocket Hardware Evaluation (SRHE), on 12 December 1969. The rocket nozzle was designed and fabricated by the United Technology Center, Sunnyvale, California. The USAF test engineer was Lt Richard K. Strome, and the United Technology Center project engineer was Mr. Joe Spano.

This technical report has been reviewed and approved.

CHARLES R. COOKE  
Chief, Solid Rocket Division  
Air Force Rocket Propulsion Laboratory

## ABSTRACT

The test firing of a rocket nozzle equipped with two fixed exit cone probes was conducted at the Air Force Rocket Propulsion Laboratory on a 36-inch inside diameter uncured propellant solid rocket motor. The exit cone probes were designed to act as shock inducing members, thereby generating side forces for thrust vector control. The probes were of two different configurations, a thin shell of silver infiltrated tungsten, and a thick block of the same material. The thin shell probe was ejected early in the firing, while the thick block version survived satisfactorily. The motor performed as desired, with a 740 psig maximum pressure, 15 second duration firing. LPC 614-A, a 16 percent aluminum, PBAN binder propellant was utilized.

## TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
I INTRODUCTION .....	1
II HARDWARE DESCRIPTION .....	2
III TEST RESULTS .....	4
A. Motor Preparation and Performance .....	4
B. Nozzle Test Results .....	5
C. Data Analysis .....	5
IV CONCLUSIONS AND RECOMMENDATIONS .....	7
REFERENCES .....	27
AUTHOR BIOGRAPHY .....	28
DISTRIBUTION .....	29
DD FORM 1473 .....	35

## TABLES

<u>Table</u>	<u>Page</u>
I Propellant Ballistic Properties .....	8
II Motor and Nozzle Performance Data .....	9

## ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Nozzle Cross Section . . . . .	10
2	Side View of Test Nozzle . . . . .	11
3	Exit Cone with Solid Block Probe . . . . .	12
4	Exit Cone with Thin Shell Probe . . . . .	13
5	Prefire View of Motor, Nozzle, and Thrust Stand . . . . .	14
6	Prefire View of Paired Probes . . . . .	15
7	Prefire View of Entrance Section . . . . .	16
8	Thick Block Probe . . . . .	17
9	Thin Shell Probe . . . . .	18
10	Chamber Pressure versus Time . . . . .	19
11	Axial Thrust versus Time . . . . .	20
12	Side Force versus Time . . . . .	21
13	Postfire Top View of Thick Block Probe . . . . .	22
14	Postfire Oblique View of Thick Block Probe and Exit Cone Erosion . . . . .	23
15	Recovered Parts of Thin Shell Probe . . . . .	24
16	Postfire View of Graphite Throat Insert . . . . .	25

## SECTION I

### INTRODUCTION

Thrust vector control (TVC) is the primary method of directing a missile in flight along the desired trajectory. Movable nozzles are a currently favored concept for providing TVC forces. Air Force studies (Reference 1) have shown that hydraulic actuation systems presently utilized on contemporary missiles can be replaced by a servo actuator. These servo nozzle control (SNC) systems operate in a manner similar to an aircraft control surface trim tab. A small servo actuation force reacting on a control component provides the power needed for control deflection.

The United Technology Center developed a SNC concept based upon inserting a probe into the supersonic exhaust of a movable solid rocket nozzle. The probe would induce a shock thereby causing a high local pressure on the exit cone surface. This high pressure area would be used as the actuation force for the movable nozzle. The environment for such a probe is very severe. Tungsten was selected by UTC for a candidate probe material. In June 1969 a SNC system utilizing a wire-wound-tungsten (WWW) probe was test fired at the AFRPL (Reference 2). The probe failed and was ejected before meaningful performance data could be obtained. A second test was conducted (reported herein) to verify survivability for a fixed silver infiltrated tungsten probe. Acceptable results would establish a basis for additional probe SNC development.

The objectives of the test were to:

1. Demonstrate the survivability of a thin shell, silver infiltrated tungsten (AgW) probe in the exit cone of a solid rocket nozzle.
2. Demonstrate the survivability of a thick block of AgW in a similar environment.

## SECTION II

### HARDWARE DESCRIPTION

The test nozzle was a conventional external configuration. A cross-section drawing is shown in Figure 1, and prefire photographs are shown in Figures 2, 3, 4 and 5.

The nozzle entrance section was fabricated from tape wrapped carbon cloth phenolic, MX 4926. The material was cured at 1000 psi and high temperature before being contoured to the final configuration. The nozzle throat insert was a 2.3 inch I.D. piece of G-90 graphite. The nozzle exit cone was a 15 degree half angle cone, fabricated from MX 4926 in the same manner as the entrance cap.

The probes were fabricated from infiltrated tungsten. Ten percent silver was the infiltrant material and 90 percent W formed the matrix. Both spikes were 5.16 inches in diameter, and of a flat end plate/cylindrical configuration. The probes were installed such that their centerlines were at an expansion ratio ( $A_{local}/A_{throat}$ ) of 5.04:1 (Figure 6), with a total area blockage of 23 percent (Figure 7). Details of the probe designs are considered to be UTC proprietary information.

It was believed that the thick block probe, being solid AgW (Figure 8) would definitely survive the test firing thus providing a firm basis for further concept development. The degree of risk associated with the thin shell probe (Figure 9) was substantially higher, but potential for an ultimately lighter weight, lower cost assembly justified its consideration by UTC.

The gas generator utilized for the test was the AFRPL 36-inch I.D. char motor. The motor was lined with a 1/2-inch wall thickness paper phenolic insulating sleeve. The sleeve was pressed into the backup insulation, Gen Gard V-61. The V-61 I.D. was machined such that it provided structural support for the paper phenolic liner. The char motor aft closure was insulated with silica-filled buna-n-rubber. LPC 614-A uncured propellant was purchased from the Lockheed Propulsion Company for the test. The formulation consisted of 16 percent aluminum, ammonium perchlorate oxidizer, PBAN binder, and traces of other materials. Nominal flame temperature was 5700°F. Exhaust composition and ballistic properties are shown in Table I.

The thrust stand used for the test is a six-component, 20,000-pound thrust capacity unit manufactured by Gilmore Industries, Cleveland, Ohio. Verification tests have confirmed the static accuracy of the stand to be the following:

- Axial thrust less than 1/2 percent error
- Pitch axis side force less than 1 percent error
- Yaw axis side force less than 1 percent error

Dynamic accuracy has not been determined.

### SECTION III

#### TEST RESULTS

##### A. MOTOR PREPARATION AND PERFORMANCE

The nozzle was received from UTC and installed on the char motor aft closure. The paper phenolic insulating sleeve was coated with LPL-22 polymer 72 hours prior to the scheduled motor loading. The polymer was cured at ambient conditions. The LPL-22 liner was used to act as a wetting agent compatible with both the insulation and the propellant, thus preventing flame propagation down the propellant/insulation interface. The propellant was air-cast into the motor and allowed to settle for a period of 24 hours. Entrapped air was allowed to escape during this time period. A "pancake" igniter consisting of an aluminum mesh coated with a pyrotechnic material was placed on the propellant surface before the aft closure was attached to the motor center chamber. The lead wires were routed through the nozzle orifice. The thrust stand was electrically calibrated after motor loading and prior to the test firing.

The motor was fired, and a smoothly regressive 740-psig maximum chamber pressure trace (Figure 10) was produced. Average chamber pressure was 700 psig over a 15 second effective burn time. A summary of significant motor preparation and performance data is found in Table II, which also contains pertinent nozzle performance information. A prediction of the maximum chamber pressure level had been made using data from an earlier 25-inch char motor firing (Reference 3). The predicted level, 750 psig, correlated well with the actual level, thereby indicating that the propellant performed similarly in the two different motor sizes.

Dynamic performance of the Gilmore thrust stand was almost as good as the static accuracy verification had indicated, in spite of oscillatory vibrations (rugging) in all axes. The stand stabilized in the axial thrust

mode immediately after ignition, and thereafter performance was typified by cyclic vibrations of approximately 30-lbf magnitude. The magnitude of the axial ringing, being less than one percent (1%) of the motor thrust was considered to be acceptable for this test. The thrust versus time trace is Figure 11.

Some vibration in the pitch axis (X axis) was also evident. The magnitude of the oscillatory vibration was approximately ten percent (10%) of the side thrust, but the regularity of the vibrations would readily allow the use of data smoothing techniques if a need for higher accuracy existed. This side force versus time trace is shown in Figure 12.

#### B. NOZZLE TEST RESULTS

The primary test objective, probe survivability, was not completely achieved. The thin-shell probe was ejected approximately 4-1/2 seconds after ignition ( $t = 5.7$  seconds). The thick block probe survived the test in excellent condition (Figure 13). The exit cone was heavily eroded in an arc upstream of the thick block probe (Figure 14). This severe localized erosion was not expected based on the results of the test described in Reference 1. This could be a problem if future firings are attempted. Parts of the thin shell probe were recovered (Figure 15), and a preliminary post test analysis indicated that a structural failure in the probe retention system had caused the component ejection. The graphite throat insert performed adequately (Figure 16), with an average surface recession rate of 1.4 mil/sec.

#### C. DATA ANALYSIS

In spite of the thin shell probe failure, some very interesting performance data was obtained. The data included thrust degradation and side force versus time,

The thrust degradation effect of the probes was analyzed by considering the magnitude of the axial thrust immediately before and after the ejection of the thin shell probe. The increase in thrust (Figure 11) was approximately 125 lbf, which indicated that the 11.5 percent area blockage at the expansion ratio of 5:1 had degraded the axial thrust by slightly less than 3 percent.

Pitch side force increased approximately 225 lbf after the probe failure. This indicated that the remaining probe was producing a side force capable of actuating a flexible seal movable nozzle.

#### SECTION IV

#### CONCLUSIONS AND RECOMMENDATIONS

Based on the char motor and test nozzle performance, the following conclusions are made:

1. The probe-actuated servo-nozzle control concept is feasible.
2. Tungsten materials can, with the proper design, survive the severe environment experienced by the probe.
3. Char motor performance was satisfactory and in no way contributed to the nozzle failure.

The following recommendations are made:

1. A lighter weight probe configuration should be developed and demonstrated.
2. Another test firing utilizing a probe and movable nozzle should be performed to validate the total system feasibility.

TABLE I. PROPELLANT BALLISTIC PROPERTIES

<u>Combustion Products (LPC 614A)</u>	<u>moles/100 gm</u>
CO -----	0.7846
HCl -----	0.5145
Cl -----	0.0446
H <sub>2</sub> O -----	0.6563
H <sub>2</sub> -----	0.9410
N <sub>2</sub> -----	0.3083
Al <sub>2</sub> O <sub>3</sub> -----	0.2820

<u>Propellant Composition</u>	<u>percent</u>
Ammonium Perchlorate -----	70.5
Aluminum -----	16.0
Binder -----	13.5

Performance Characteristics

Nominal $r_b$ -----	0.30 in @ 800 psig
Nominal $n$ -----	0.33 @ 800 psig

**TABLE II. MOTOR AND NOZZLE PERFORMANCE DATA**

Prefire Throat Diameter	2.302 inches
Postfire Throat Diameter	2.344 inches
Propellant Formulation	LPC 614A
As-Cast Propellant Depth	5.0 inches
Burn Surface Diameter	36.0 inches
Propellant Weight ( $W_p$ )	360 pounds
Predicted Maximum $P_c$	750 psig
Actual Maximum $P_c$	740 psig
Average $P_c$	704 psig
Effective Duration	15 seconds
Total Impulse	69,000 lb-sec
*Calculated Specific Impulse	192 seconds
Ambient Temperature	66°F
Ambient Pressure	13.6 psia

\*This is delivered  $I_{sp} = \frac{\int F dt}{W_p}$  where  $F$  = thrust

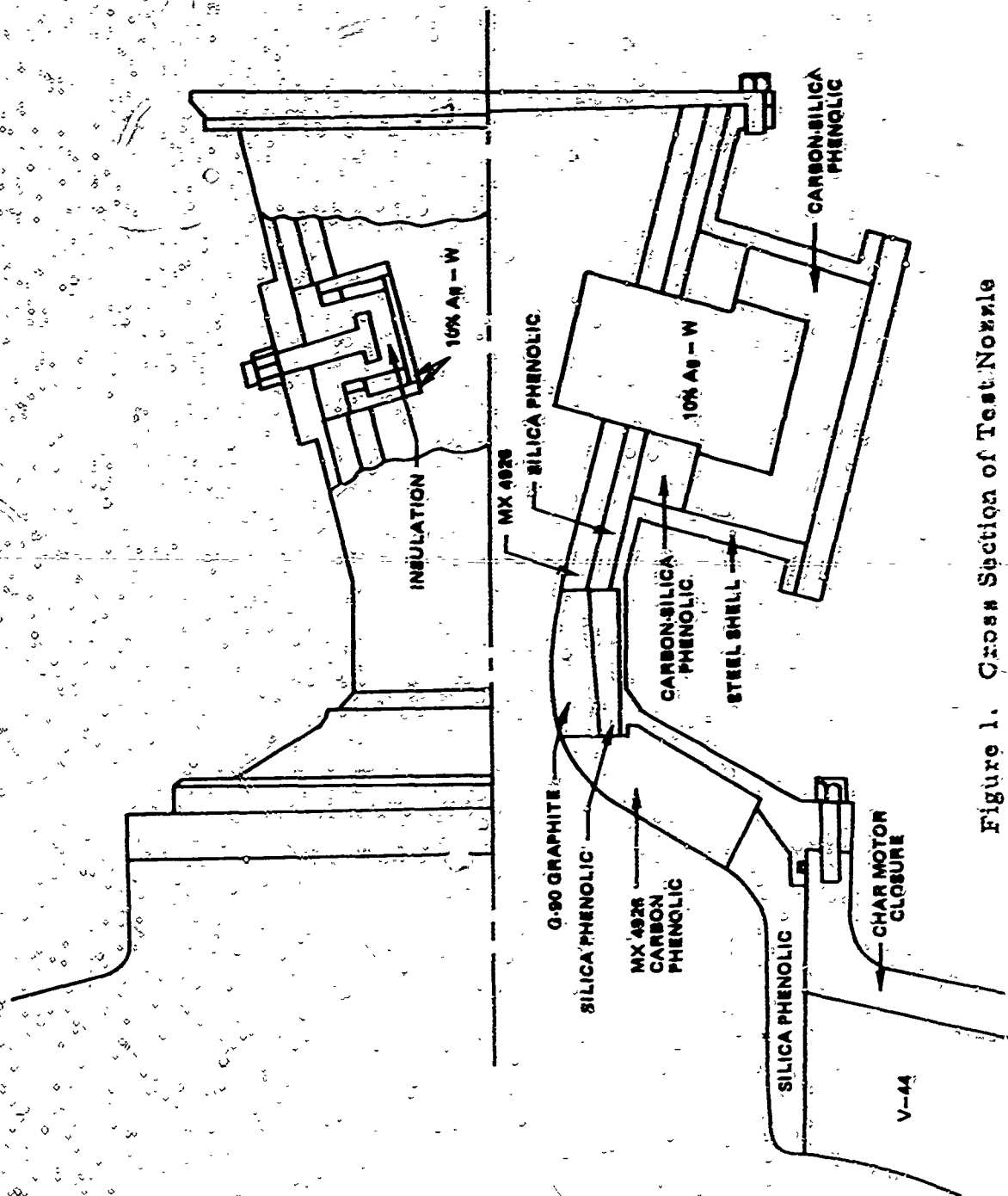


Figure 1. Cross Section of Test Nozzle

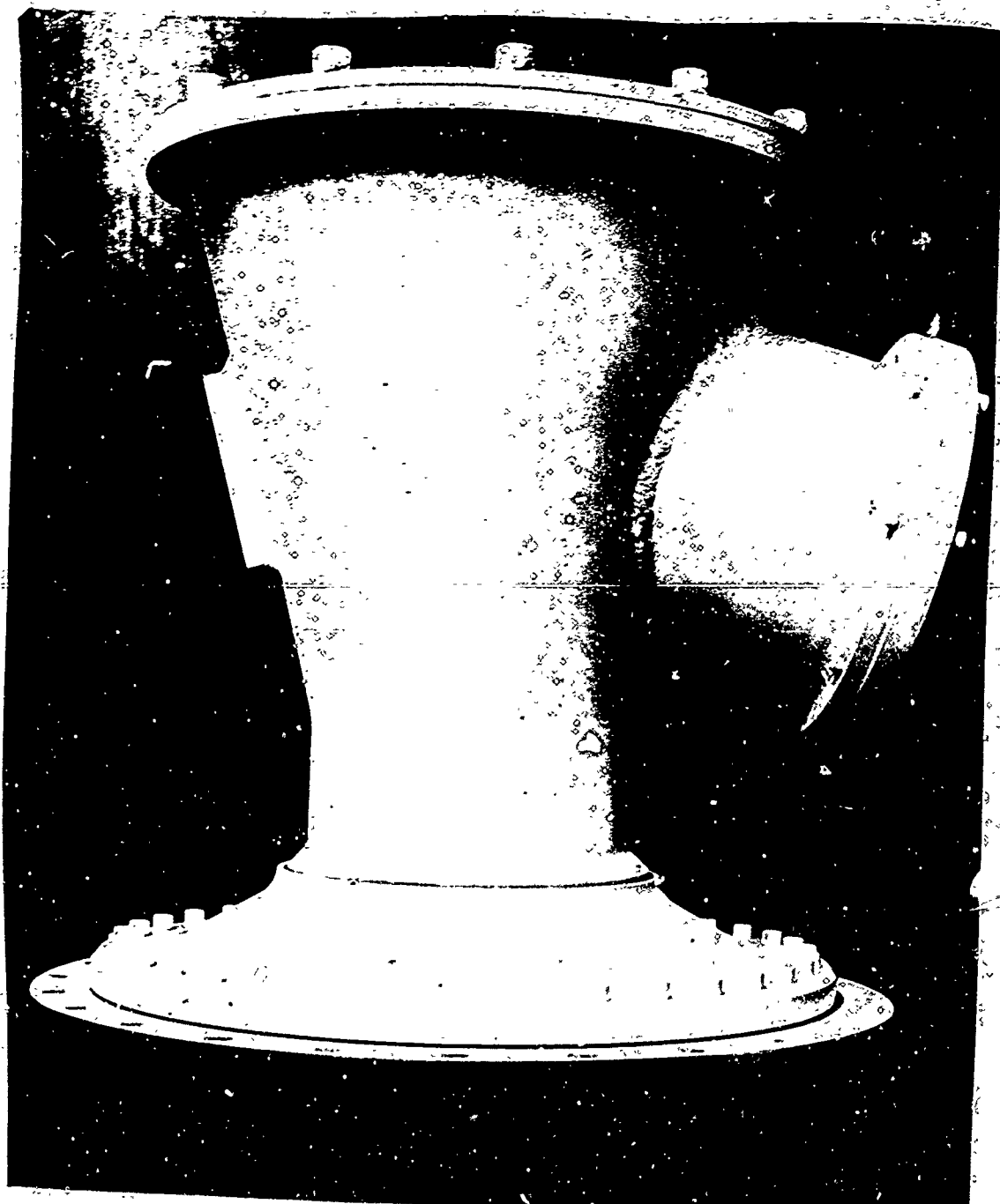


Figure 2. Side View of Test Nozzle

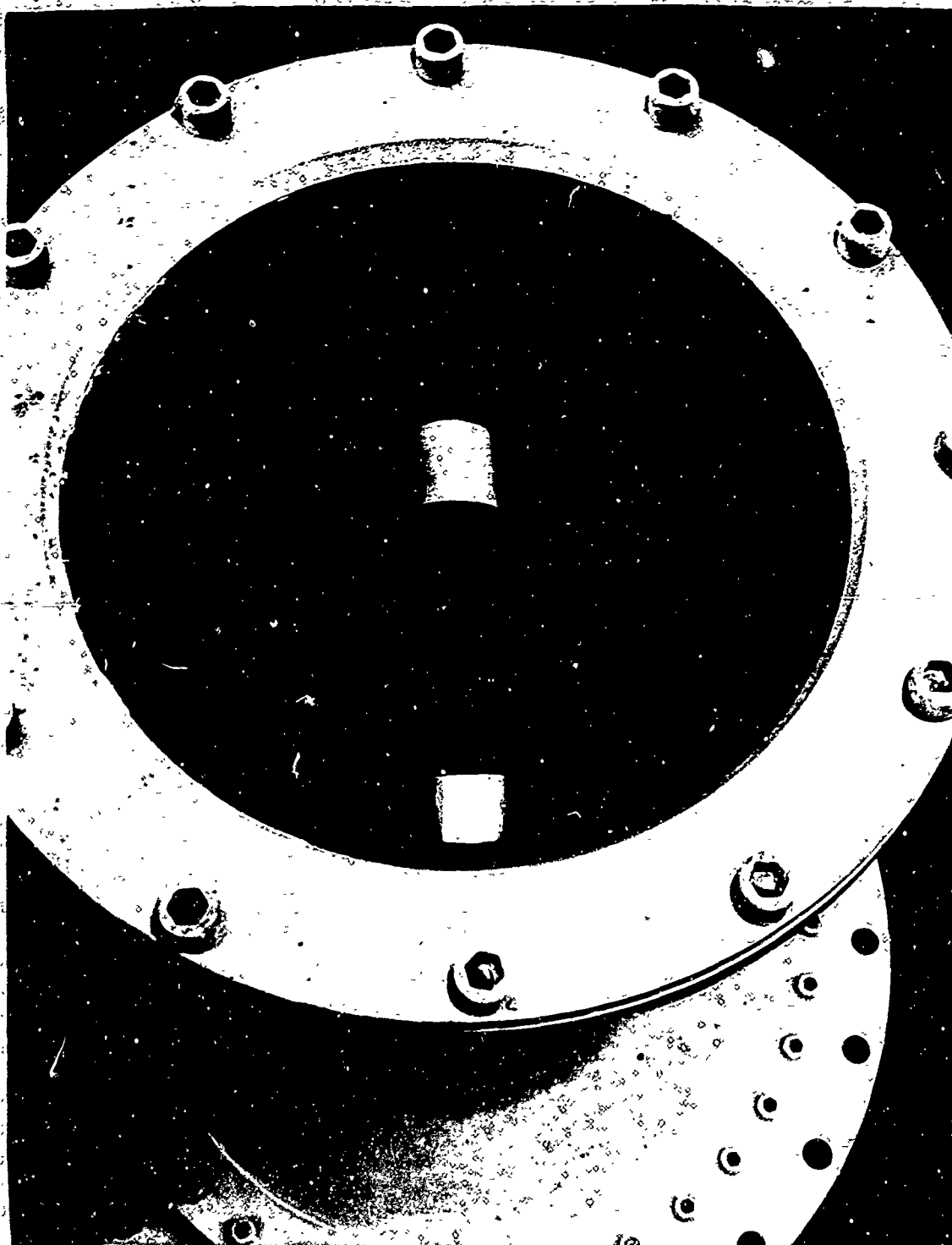


Figure 3. Exit Cone with Solid Block Probe

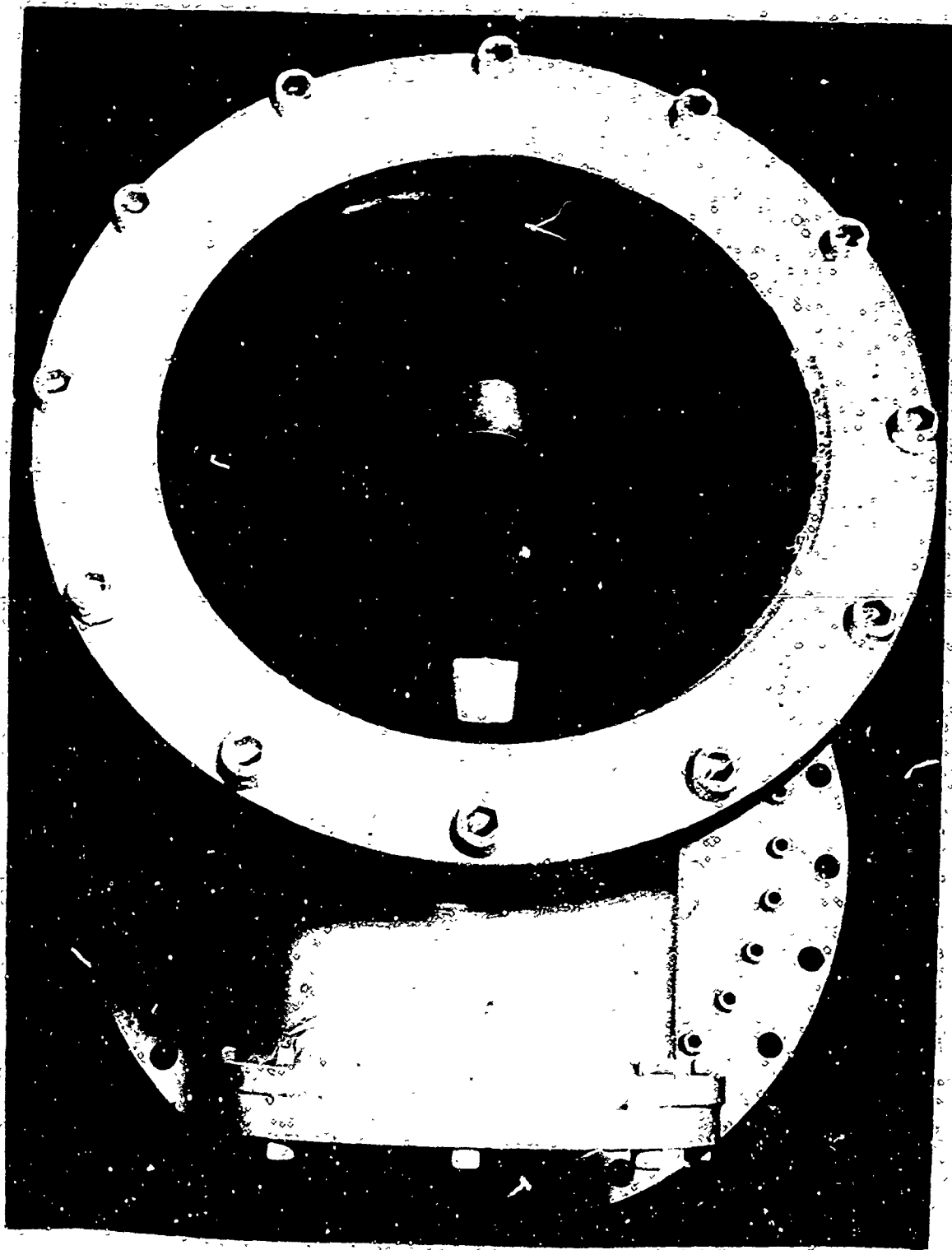


Figure 4. Exit Cone with Thin Shell Probe



Figure 5. Prefire View of Motor, Nozzle, and Thrust Stand

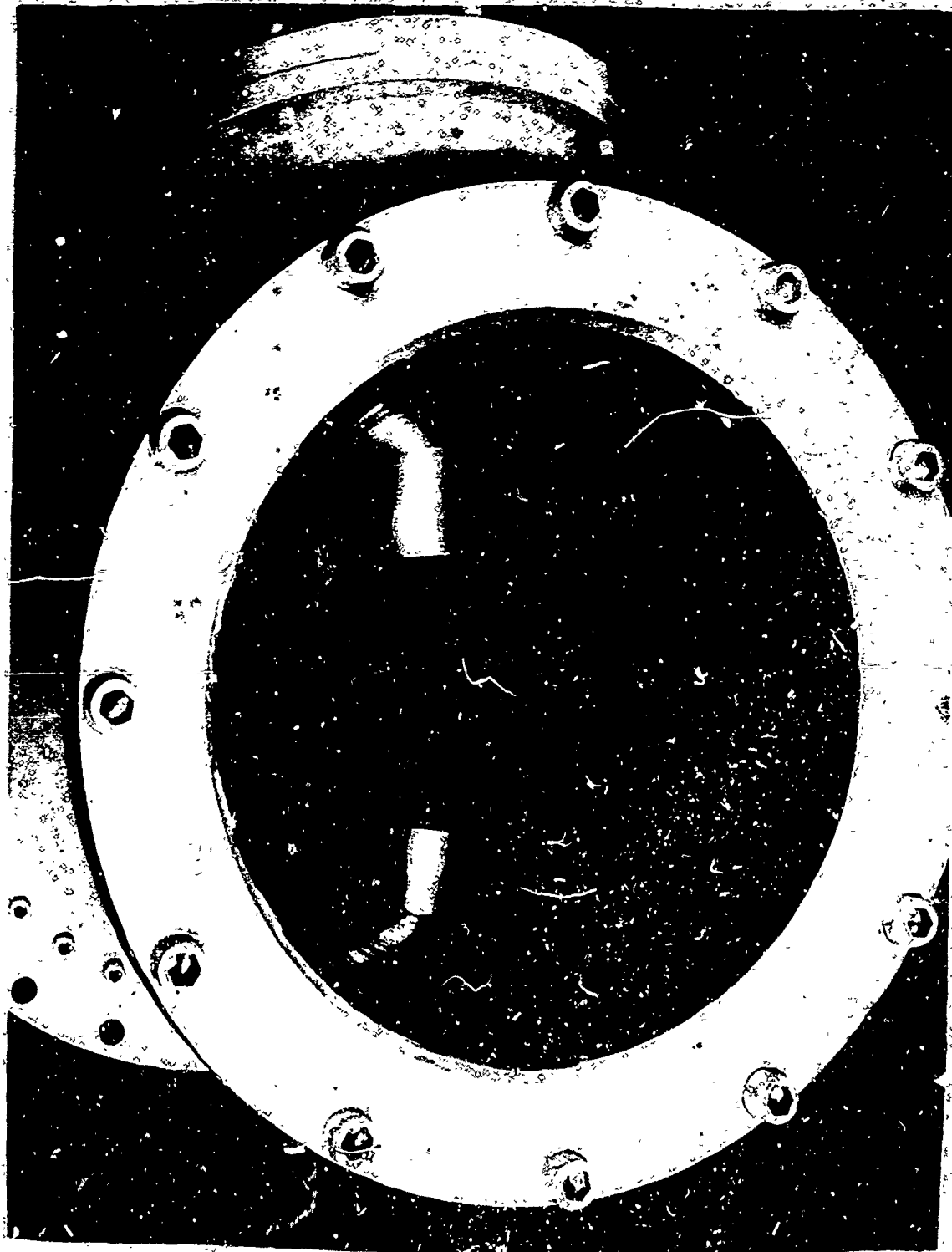


Figure 6. Prefire View, Paired Probes  
1b

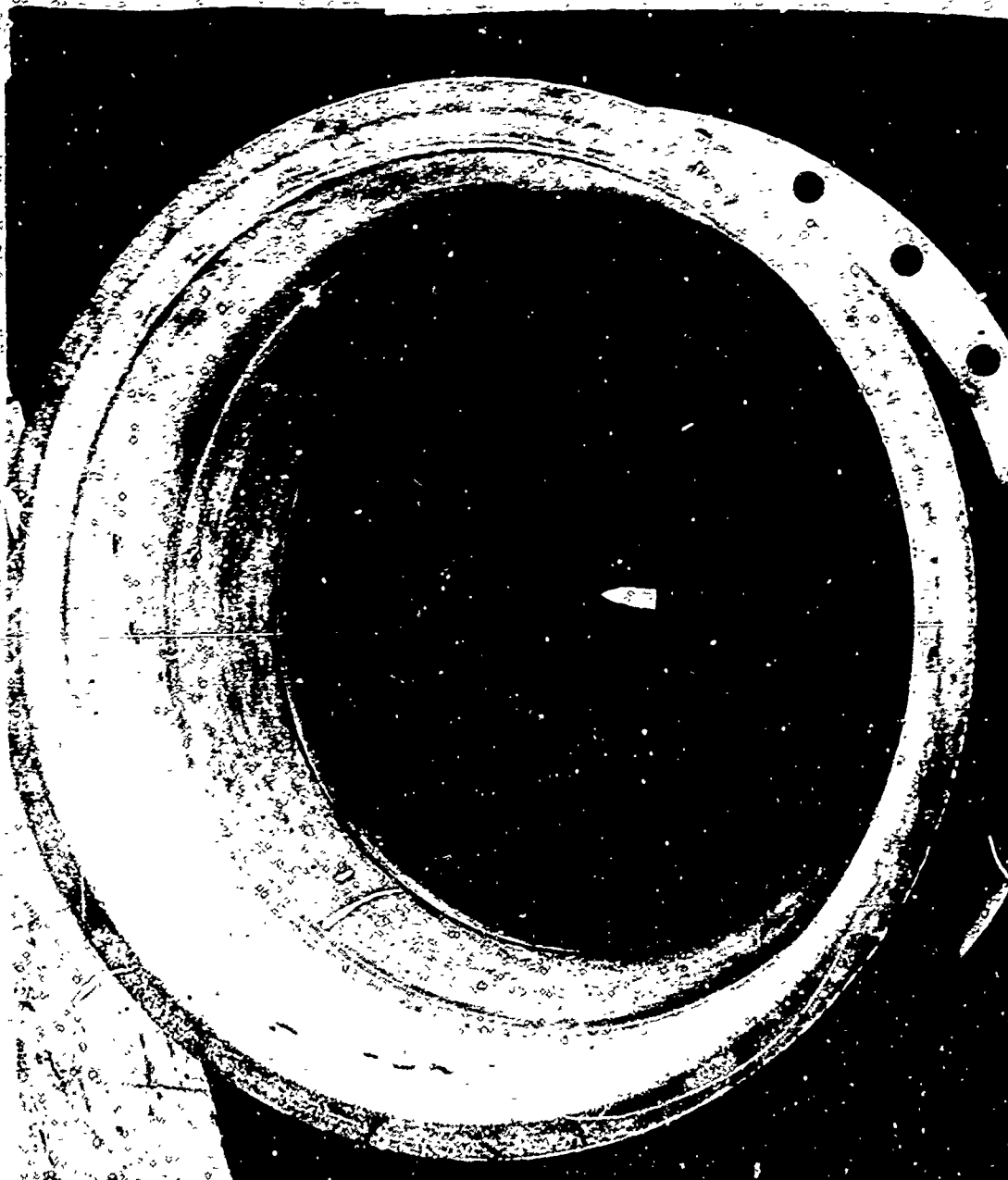


Figure 7. Profile View of Entrance Section

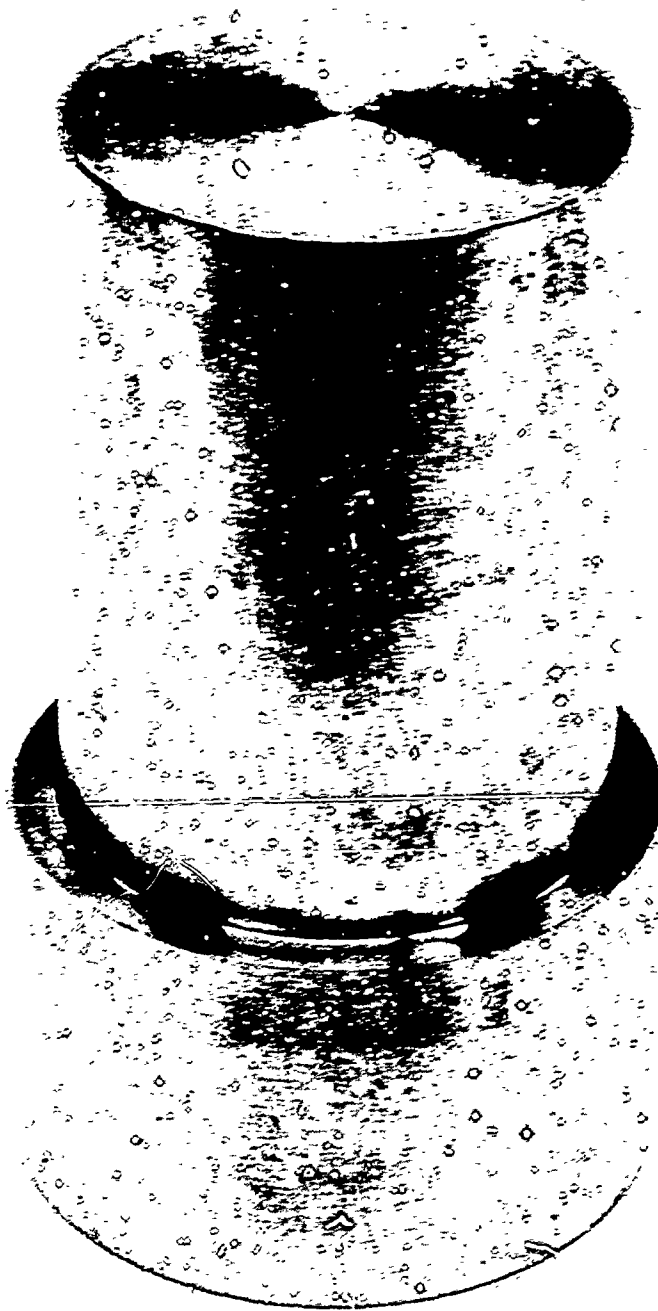


Figure 8. Thick Block Probe

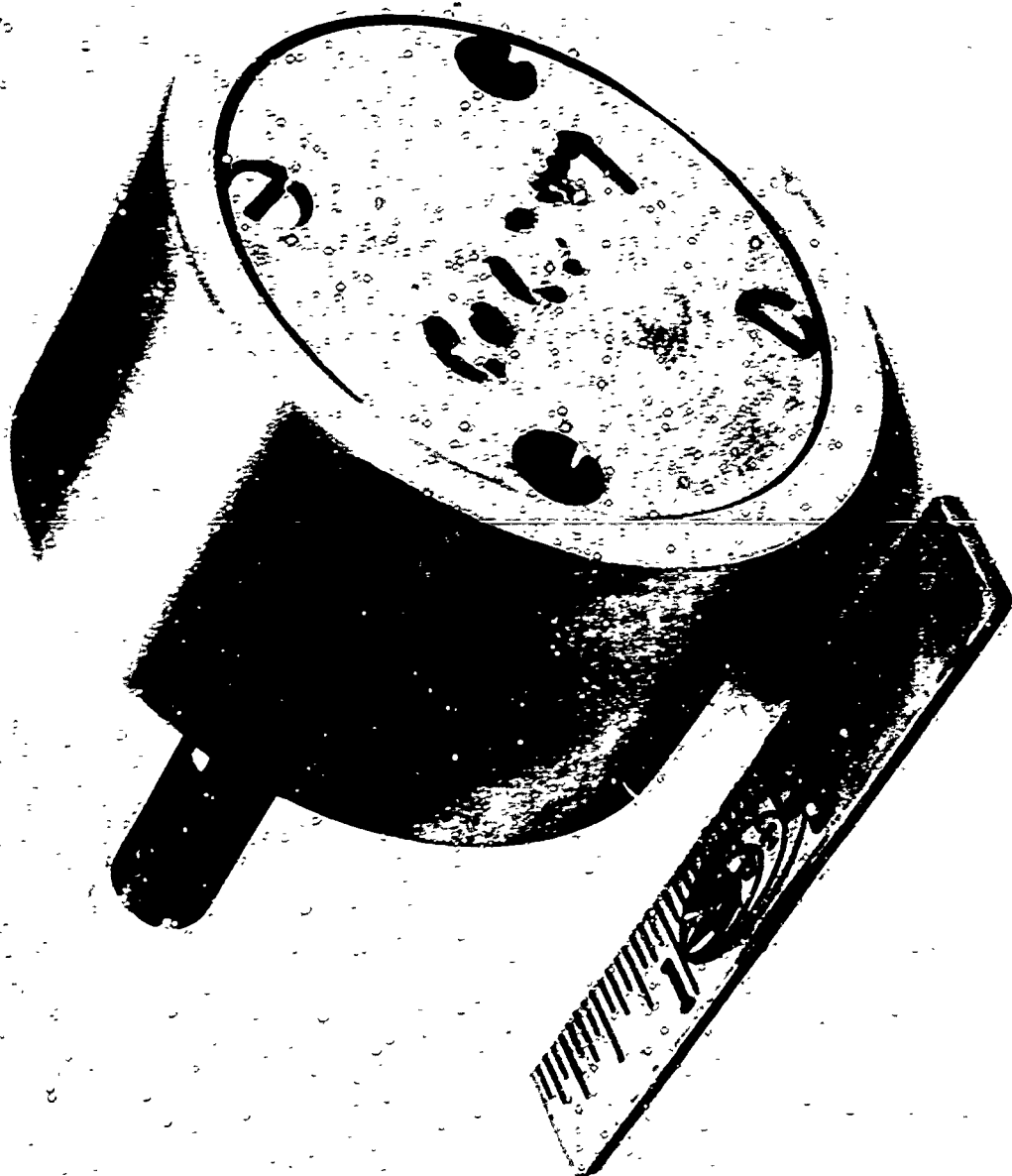


Figure 9. Thin Shell Probe

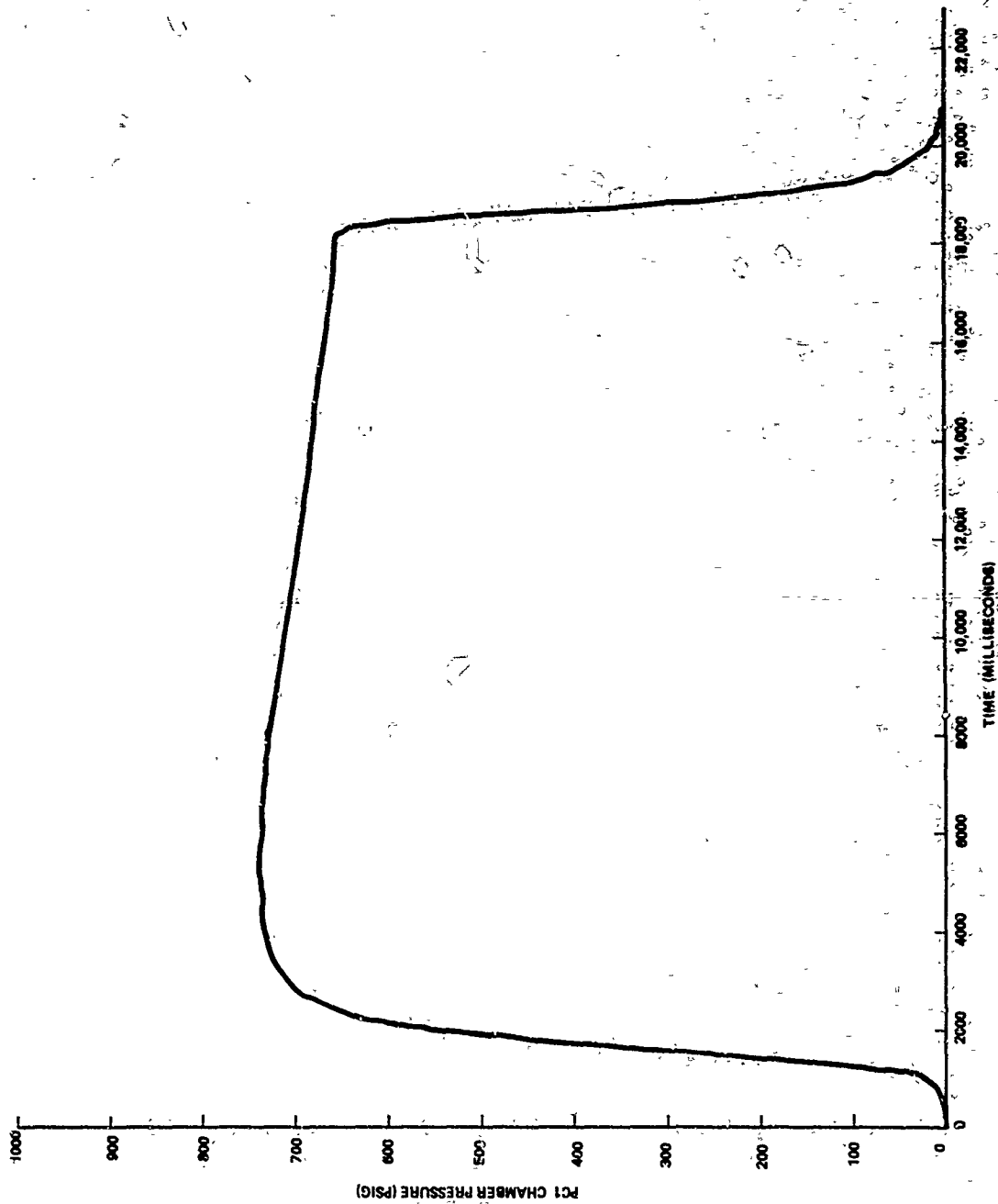


Figure 10. Chamber Pressure versus Time

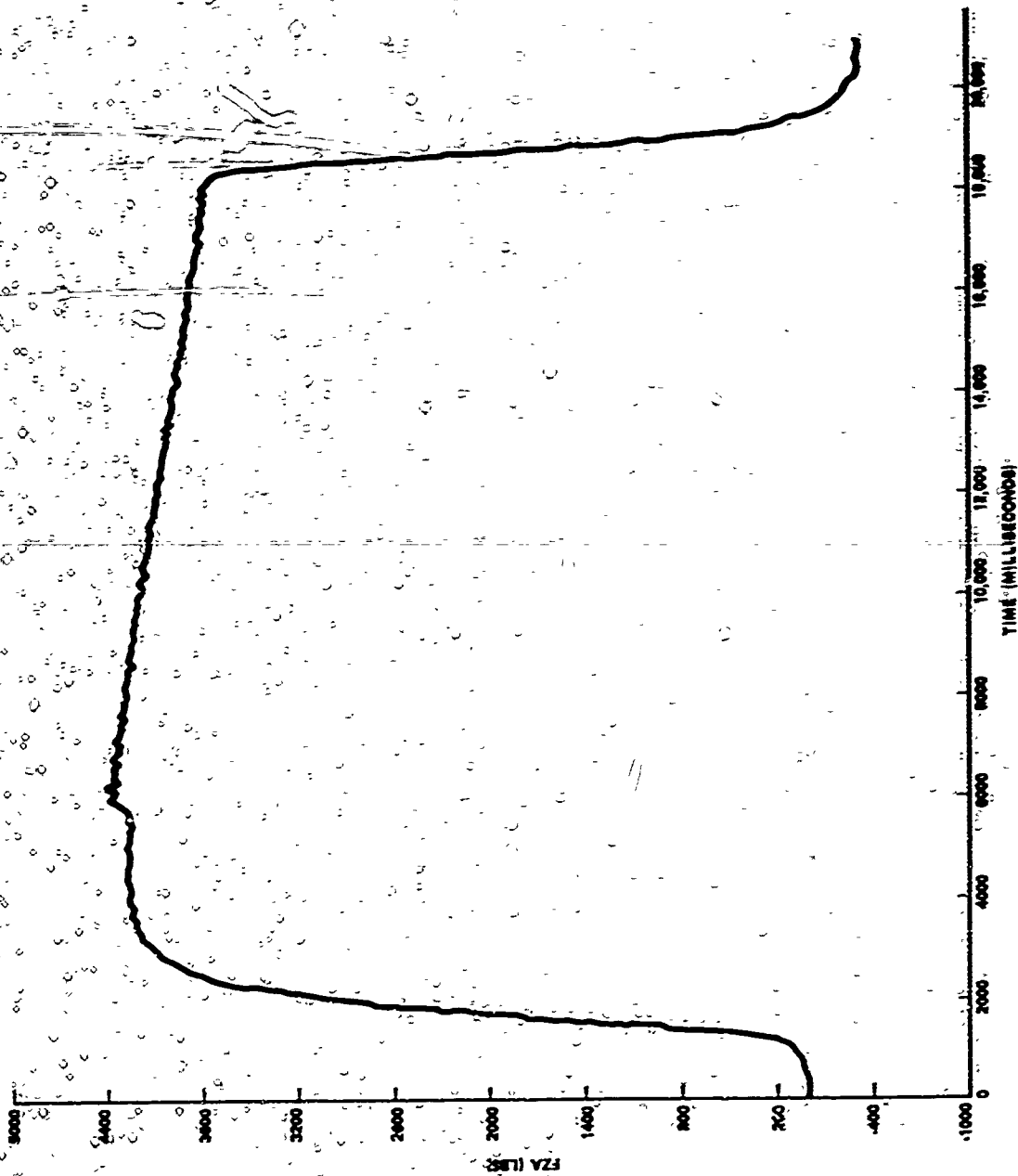


Figure 11. Axial Thrust versus Time

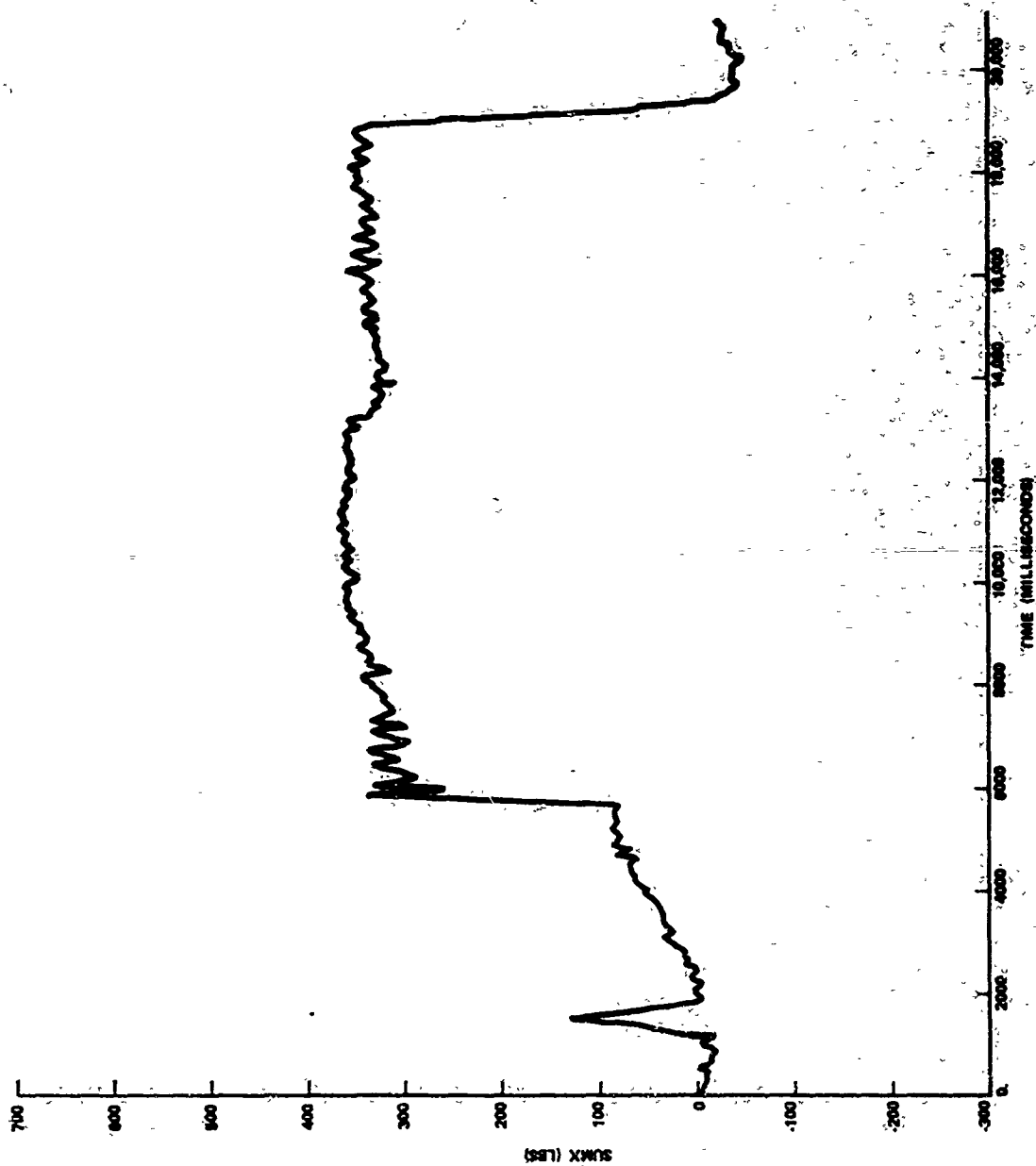


Figure 12. Side Force versus Time

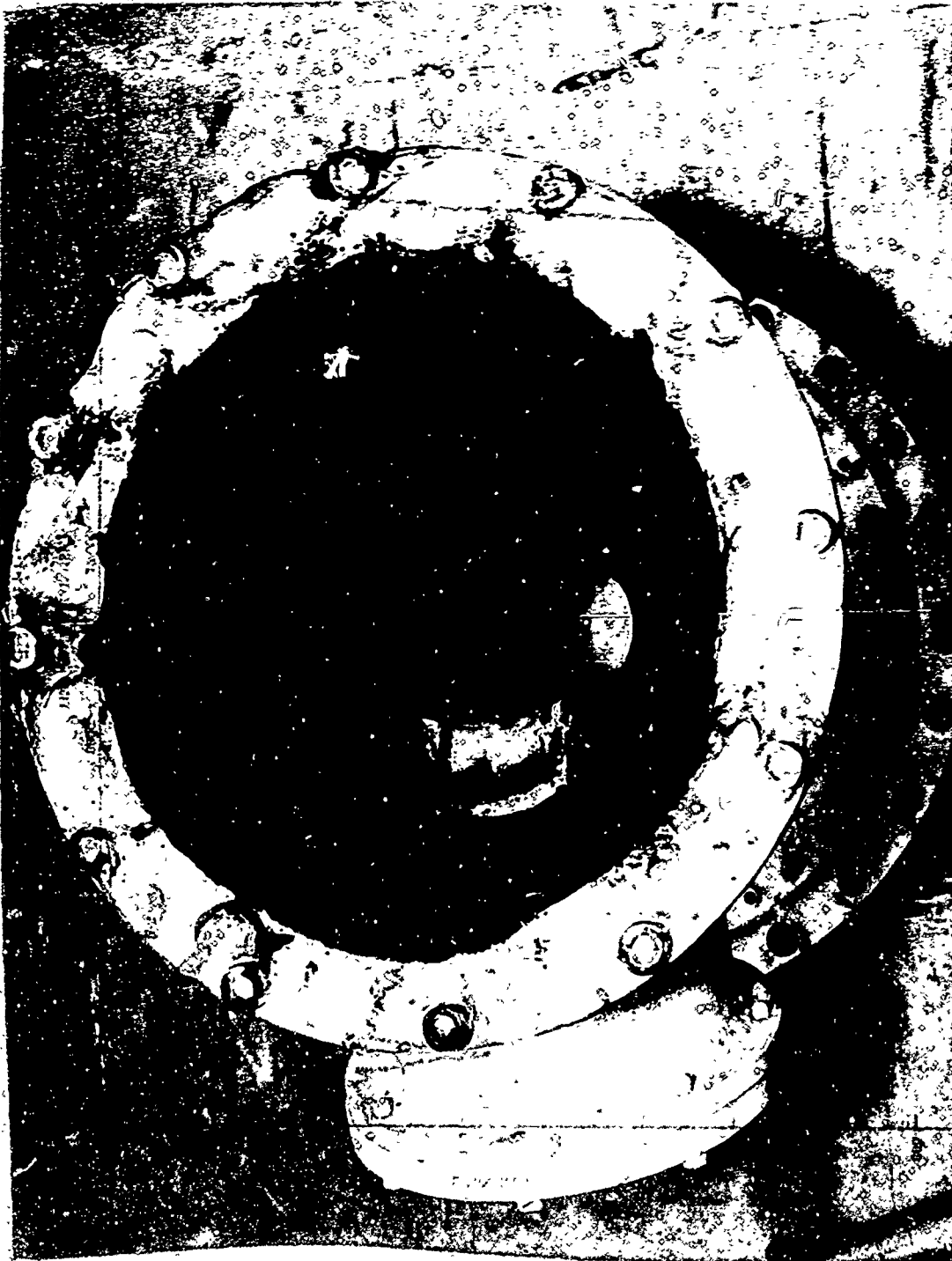


Figure 13. Postfire Top View of Thick Block Probe

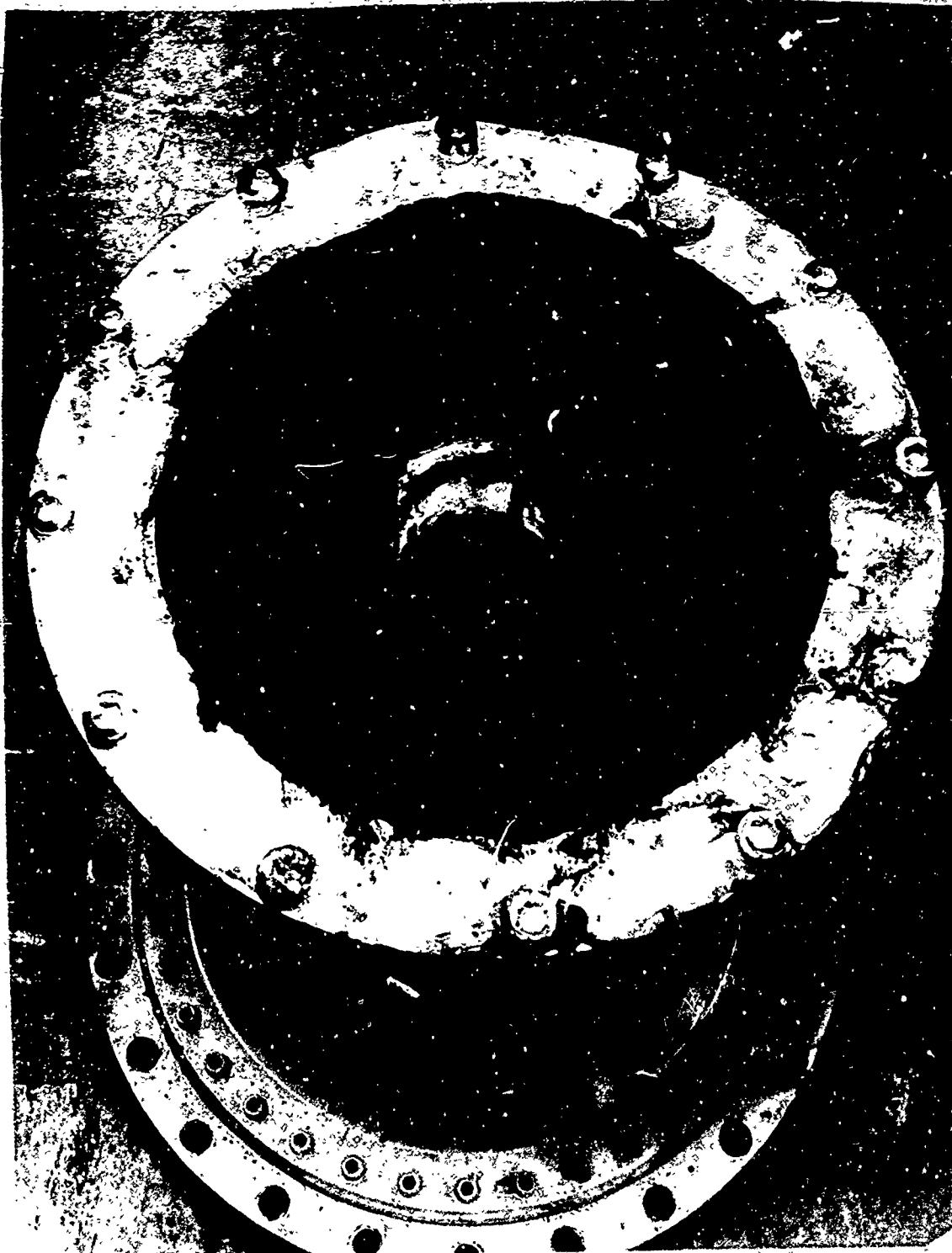


Figure 14. Postfire Oblique View of Thick Block  
Probe and Exit Cone Erosion

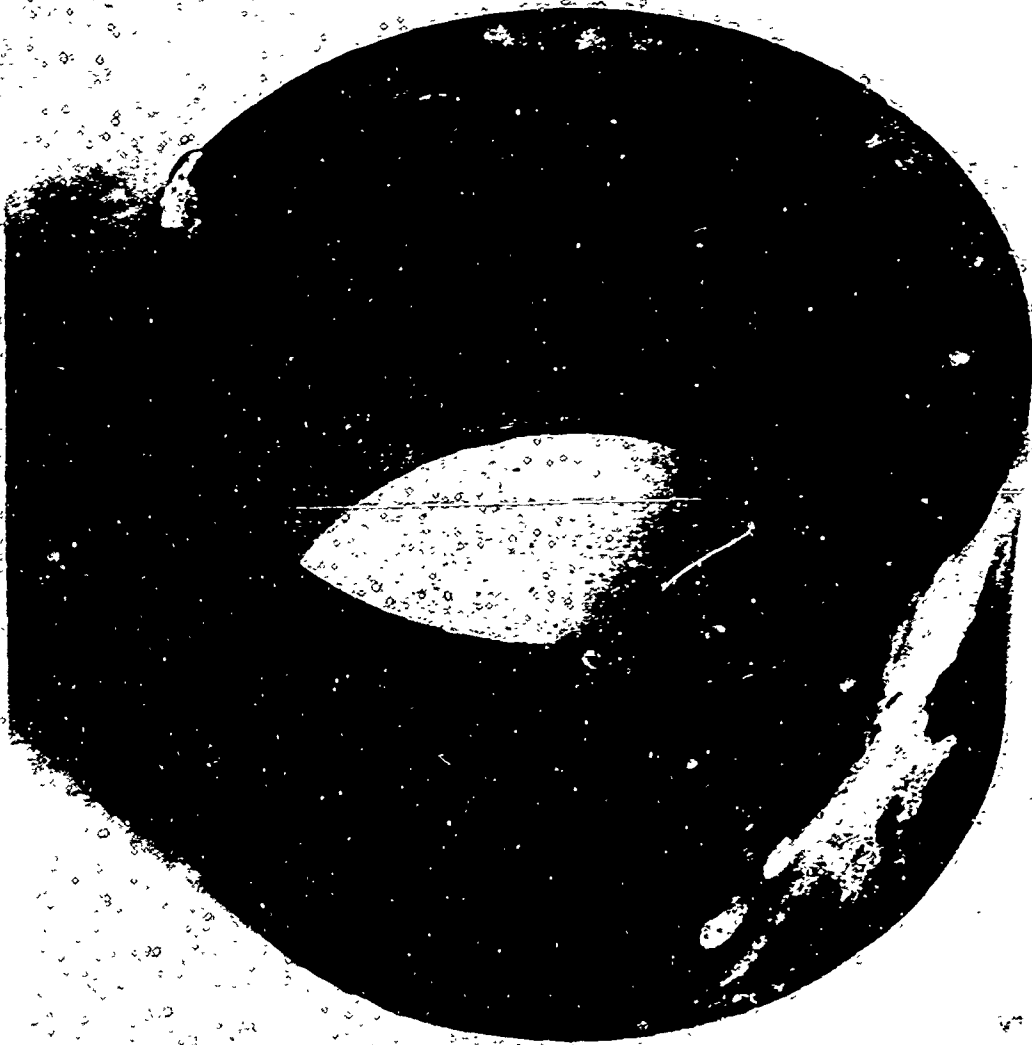


Figure 15. Recovered Parts of Thin Shell Probe

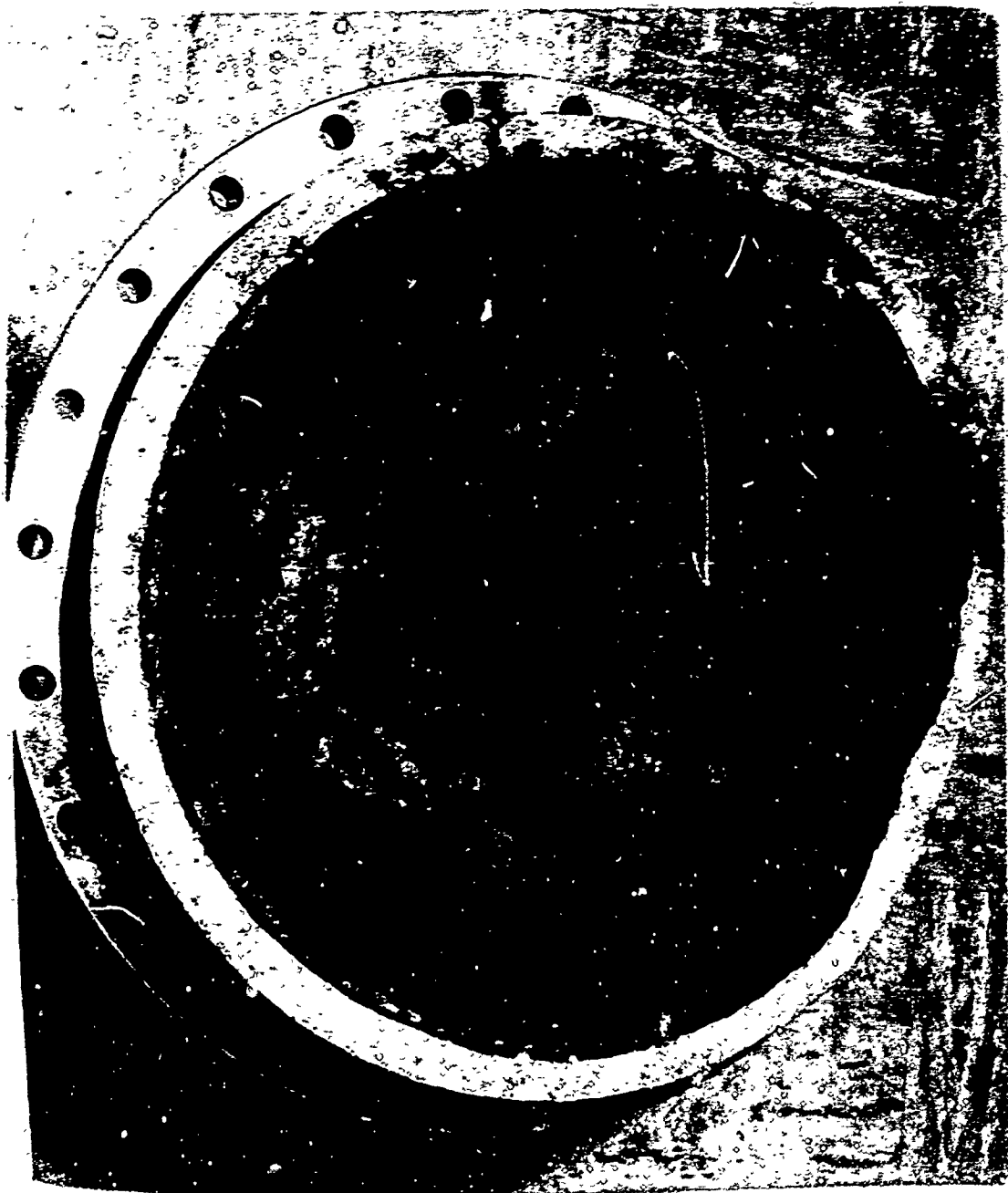


Figure 16. Postfire View of Graphite Throat-Insert

## REFERENCES

1. R. Lahde and H. Hollstein; "Servo Nozzle Control"; AFRPL-TR-69-135, AD 502193; Lockheed Missiles and Space Company, Palo Alto, California; May 1969; Confidential Report.
2. J. Ellison; "Test Firing of a Spike-Actuated Flexible Seal Nozzle"; AFRPL-TR-69-191; AD 862282; Air Force Rocket Propulsion Laboratory, Edwards, California; September 1969; Unclassified Report.
3. D. Zorich and J. Ellison; "Evaluation of Pyrolytic Graphite Coated Rocket Nozzle Throat Inserts (Test Nozzles 2 and 3); AFRPL-TR-69-237; AD ; Air Force Rocket Propulsion Laboratory; Edwards, California; November 1969; Unclassified Report.

PRECEDING PAGE BLANK

## AUTHOR BIOGRAPHY

JOHN R. ELLISON, LT, USAF  
Air Force Rocket Propulsion Laboratory  
Edwards, California

Project Engineer, Motor Component Development Branch, Hardware Section, Solid Rocket Division. B.S. in Aerospace Engineering, Auburn University, Auburn, Alabama, 1967. Engaged in program formulation, technical management, and concept evaluation for contractual efforts in the field of solid propellant rocket technology. Also manages and directs an extensive in-house solid rocket hardware testing project. Member of American Institute of Aeronautics and Astronautics (AIAA), Tau Beta Pi, Sigma Gamma Tau, Phi Eta Sigma, and Omicron Delta Kappa.

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Air Force Rocket Propulsion Laboratory Edwards, CA 93523		2a. REPORT SECURITY CLASSIFICATION Unclassified	
		2b. GROUP N/A	
3. REPORT TITLE Test Firing of a Supersonic Probe Thrust Vector Control Concept			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Test Report December 1969			
5. AUTHOR(S) (First name, middle initial, last name) J. R. Ellison, Lt, USAF			
6. REPORT DATE July 1970		7a. TOTAL NO. OF PAGES 42	7b. NO. OF REFS 3
8a. CONTRACT OR GRANT NO.		9a. ORIGINATOR'S REPORT NUMBER(S) AFRPL-TR-70-63	
8b. PROJECT NO: 305903AMG		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
10. DISTRIBUTION STATEMENT This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of AFRPL (RPOR-STINFO), Edwards, California 93523.			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Air Force Rocket Propulsion Laboratory Air Force Systems Command, USAF Edwards AFB, California	
13. ABSTRACT The test firing of a rocket nozzle equipped with two fixed exit cone probes was conducted at the Air Force Rocket Propulsion Laboratory on a 36-inch inside diameter uncured/propellant solid rocket motor. The exit cone probes were designed to act as shock inducing members, thereby generating side forces for thrust vector control. The probes were of two different configurations, a thin shell of silver infiltrated tungsten, and a thick block of the same material. The thin shell probe was ejected early in the firing, while the thick block version survived satisfactorily. The motor performed as desired, with a 740 psig maximum pressure, 15 second duration firing, LPC 614-A, a 16 percent Aluminum, PBAN binder propellant was utilized.			

~~Unclassified~~  
~~Security Classification~~

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Thrust Vector Control						
Char Motor						
Supersonic Nozzle Probe						
Silver Infiltrated Tungsten						
Servo Nozzle Control						

~~Unclassified~~  
~~Security Classification~~